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VALIDATION OF THE DIGITAL OPACITY COMPLIANCE SYSTEM UNDER REGULATORY ENFORCEMENT CONDITIONS

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14. ABSTRACT

U.S. Environmental Protection Agency (EPA) Emission Measurement Center (EMC), in conjunction with EPA Regions VI and VIII, the State of Utah and the US Department of Defense, have conducted a series of long-term pilot and field tests to determine the accuracy and reliability of a visible opacity monitoring system consisting of a conventional digital camera and a separate computer software application for plume opacity determination. This technology, known as the Digital Opacity Compliance System (DOCS), has been successfully demonstrated at EPA-sponsored Method-9 "smoke schools" as well as at a number of government and commercially operated industrial facilities. Results from the current DOCS regulatory pilot study demonstrate that, under regulatory enforcement conditions, the average difference in opacity measurement between the DOCS technology and EPA Reference between the DOCS technology and EPA Reference Method 9 (Method 9) is 1.12%. This opacity [Continued on p. ii]

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Given the costs and technical limitations associated with use of Method 9, there is a recognized need to develop accurate, reproducible, and scientifically defensible alternatives to the use of human observers. The use of digital imaging/processing brings current technology to bear on this important regulatory issue. Digital technology offers increased accuracy, a permanent record of measurement events, lower costs, and a scientifically defensible approach for opacity determination.

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ABSTRACT

U.S. Environmental Protection Agency (EPA) Emission Measurement Center in conjunction with EPA Regions VI and VIII, the state of Utah, and the U.S. Department of Defense have conducted a series of long-term pilot and field tests to determine the accuracy and reliability of a visible opacity monitoring system consisting of a conventional digital camera and a separate computer software application for plume opacity determination. This technology, known as the Digital Opacity Compliance System (DOCS), has been successfully demonstrated at EPA-sponsored Method-9 "smoke schools," as well as at a number of government and commercially operated industrial facilities.

Results from the current DOCS regulatory pilot study demonstrated that, under regulatory enforcement conditions, the average difference in opacity measurement between the DOCS technology and EPA Reference Method 9 (Method 9) was 1.12%. This opacity difference, which was computed from the evaluation of 241 regulated air sources, was found to be statistically significant at the 99% confidence level. In evaluating only those sources for which a nonzero visible opacity level was recorded, the average difference in opacity measurement between the DOCS technology and Method 9 was 1.20%. These results suggest that the two opacity measurement methods are essentially equivalent when measuring the opacity of visible emissions.

Given the costs and technical limitations associated with use of Method 9, there is a recognized need to develop accurate, reproducible, and scientifically defensible alternatives to the use of human observers. The use of digital imaging/processing brings current technology to bear on this important regulatory issue. Digital technology offers increased accuracy, a permanent record of measurement events, lower costs, and a scientifically defensible approach for opacity determination.

IMPLICATIONS

Results from the DOCS pilot study demonstrated that, under regulatory enforcement conditions, the average difference in opacity measurement between the DOCS technology and Method 9 certified human observers was 1.12%. This opacity difference, which was computed from the evaluation of 241 regulated air sources, was found to be statistically significant at the 99% confidence level. Because of the successful deployment of DOCS under regulatory enforcement conditions, EPA has recently developed a camera-based visible opacity measurement approach titled "Determination of Visible Emission Opacity from Stationary Sources Using Computer-Based Photographic Analysis Systems" (available at http://www.epa.gov/ttn/emc/prelim/pre-008.pdf). The proposed opacity measurement approach is scheduled to be promulgated by EPA in 2006 as a conditional method after completion of the public comment period.

INTRODUCTION

Most U.S. Department of Defense (DoD) installations/facilities are subject to Title V of the 1990 Clean Air Act Amendments. Although there are a variety of air sources regulated under Title V, the most common are those that generate visible emissions.[1] To demonstrate compliance with federal visible emission limits, the opacity associated with regulated air sources must be verified through use of an approved regulatory method.

For the majority of regulated air sources, the primary method for determining compliance with permitted opacity levels is U.S. Environmental Protection Agency (EPA) Reference Method 9 (Method 9).[2] Method 9 relies on trained human observers to visually determine compliance by measuring the opacity of a smoke plume once every 15 sec for a specified time period. The 15-sec opacity recordings are averaged to determine a single opacity measurement that is then compared against the permitted opacity level of the facility.

To become legally certified as a Method 9 visual opacity observer, an individual must complete classroom training and successfully pass a visual opacity field examination conducted at an EPA-approved smoke school once every 6 months. The field examination requires that the Method 9 candidate determine the visible opacity of 25 white and 25 black smoke plumes with an error rate of ≤15% for any individual opacity observation and an aggregate opacity measurement error rate of ≤7.5% for all

50 readings. Although Method 9 has an extensive history of successful use, its opacity measurements are inherently subjective, a characteristic that renders its results vulnerable to claims of inaccuracy, bias, and, in some cases, outright fraud.

Beyond the technical concerns associated with the limited accuracy and reliability of Method 9 results, the recurring training costs necessary to support Method 9 certification can become a significant financial burden on the compliance budget of a facility. With historically flat and currently declining federal environmental compliance budgets, development of new cost-effective and regulatorially supportable methods for verifying compliance with permitted visible opacity levels is receiving increased attention by environmental compliance enforcement personnel, as well as the regulated community.[3]

The Digital Opacity Compliance System (DOCS), which is an innovative technology that uses digital imaging technology for quantifying visible opacity, has been developed and field tested as a technically defensible and economically competitive method for verifying compliance with permitted opacity levels.[4–6] The DOCS uses a commercial-off-the-shelf digital camera to capture images of visible opacity, which are then downloaded to a standard personal computer and analyzed using specialized computer software. The DOCS technology has been demonstrated to be not only as accurate and reliable as Method 9 but has the added advantage of furnishing the technology user with a permanent visual record of the emissions.

BACKGROUND

The presence of visible air emissions from regulated stationary air sources provides irrefutable evidence that airborne particles are being discharged into the atmosphere.[1,7] The public has not only expressed its concern regarding the negative psychological effects of visible emissions, but, under many circumstances, particulate emissions have been identified as the cause of increased human health and environmental risk. Because of public concerns regarding the potential health and environmental impacts associated with visible air emissions, current federal statutes, as well as many state and local air quality control laws, actively regulate the opacity of plumes (i.e., point sources of air pollution).

The current technology field demonstration was designed to evaluate the technical performance of the DOCS technology under regulatorially enforceable conditions. The implementation of the field demonstration, which was formulated to complement previous DOCS field activities, was requested by EPA Emission Measurement Center (EMC) to establish the technical basis for a new regulatorially approved method for measuring visible opacity.[3,8] Independent regulatory and technical oversight for the DOCS 1-yr regulatory pilot demonstration study was provided by a DOCS regulatory and technical advisory panel, which consisted of EPA scientists, engineers, and air quality enforcement personnel from Regions VI (Texas) and VIII (Colorado), as well as state regulators from California, Texas, and Utah. Beyond the regulatory community, DoD air compliance personnel from Elmendorf Air Force Base, AK, Fort Hood, TX, Hill Air Force Base, UT, and Aberdeen Proving Ground, MD, participated in the DOCS regulatory and technical advisory panel deliberations.

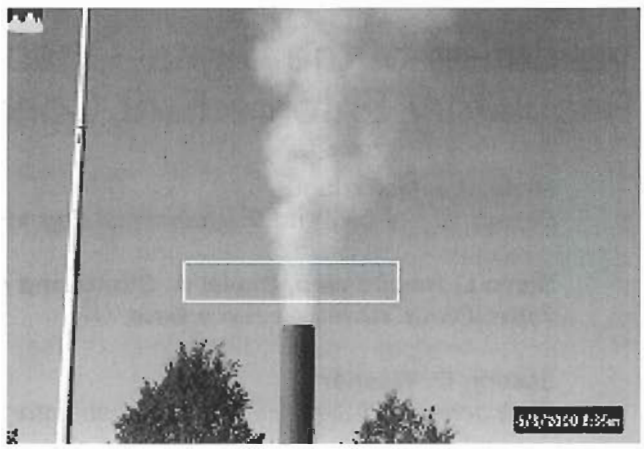

Figure 1. Drawing of the opacity analysis box using the DOCS technology.

Basic Theory of the DOCS Technology

During the application of the DOCS technology, digital photographs of visible emissions are taken from positions that allow the plume to be clearly viewed against a sky background. These photographs are downloaded to a laptop or desktop computer where they can be analyzed for opacity using the DOCS software. The initial steps in analyzing the digital image for opacity include: (1) activating the DOCS opacity analysis program, (2) retrieving those digital photographs that are to be evaluated, and (3) using the DOCS program to draw an analysis box (or grid) around that portion of the visible emissions that will be analyzed for opacity (Figure 1).

After selection of the analysis box, the DOCS software first distinguishes whether the plume is lighter or darker than the background. The DOCS software accomplishes this by transforming the image to a gray scale with enhanced dark and light colors. By assuming that the spatial color intensity of the pixels located at the vertical edges of the analysis box correspond with background and those located in the center represent visible emissions, the software is able to determine statistically whether the emissions are lighter or darker than the background.

Once the contrast between the emissions and background has been established, the DOCS software transforms the spatial color intensity data (which is stored in image files) to an optical space characterized by the dimensions of hue, saturation, and value (HSV). In HSV space, the DOCS software uses a principal component analysis approach to identify the most important parameter gradient (i.e., the parameter gradient that reflects the maximum variability in color intensity). That parameter (or principal component) is then used to establish a linear scale of opacity from which an overall aggregate opacity of the plume can be determined.[9]

Practical Application of the DOCS Technology

Under normal circumstances, the DOCS technology user rarely needs to understand the complex mathematical

relationships associated with digital image transformation. Rather, the technology user simply draws an analysis box around the area of the plume to be analyzed for opacity. The DOCS software then establishes the plume background based on the spectral information contained in the pixels. The size and shape of the analysis box, which is controlled by the user of the DOCS software, must be chosen judiciously, because the final opacity measurement will ultimately depend on what part of the image the DOCS software identifies as background.

A compelling advantage of DOCS over other proposed camera-based opacity determination systems is that its application does not require the use of physical targets to achieve accurate and reproducible opacity measurements. In principle, the use of targets for visible obscurence measurement would seem to have scientific merit; however, in practice, the economic burden associated with target maintenance and logistical operations (particularly for those targets placed on stacks of considerable height, i.e., >15 ft) have never been satisfactorily addressed and, in some cases, could be significant.[14,15]

Finally, the most persuasive argument supporting a nontarget-based digital camera approach to determining stack plume opacity is the availability of Method 9. Because Method 9 has been successfully litigated by both federal and state regulatory agencies, both regulated facilities and the regulating community are inherently averse to using any technology deemed less user friendly and/or more costly to implement than Method 9. The DOCS technology, which is essentially a "point and shoot" photographic approach, is as easy to apply as Method 9 in the field, while providing the user with improved compliance documentation, as well as enhanced objectivity and reproducibility in opacity determination.

Previous DOCS Technology Field Demonstrations

From January 2001 through December 2003, a DOCS field demonstration was conducted during which the digital camera-based opacity measurement technology was evaluated at EPA-approved Method 9 smoke schools, as well as DoD industrial and private commercial facilities.[3–8] Results from these field tests confirmed that the DOCS technology consistently met the quantitative performance standards for accuracy and reliability established for Method 9. Furthermore, over the opacity ranges of regulatory importance (i.e., 0–40% opacity), the DOCS accuracy was demonstrated to be statistically better than that achieved by Method 9-certified human observers. During deployment of the DOCS technology at DoD industrial and private commercial facilities, the DOCS accuracy in measuring visual opacity was found to not only be comparable to Method 9-certified human observers, but the DOCS technology exhibited several important practical advantages for DoD facilities including: (1) improved measurement objectivity and reliability, (2) lower deployment and maintenance costs, and (3) generation of a permanent digital image of visible opacity that can be easily referenced in challenging regulatory enforcement actions.

After a comprehensive technical review of the DOCS technology field demonstration results and in light of continuous appeals by EPA regional offices, state regulatory agencies, and the regulated community for the establishment of a camera-based visible opacity field measurement method, EPA EMC recommended the development and implementation of a DOCS 1-yr regulatory pilot study in which the accuracy and reliability of the DOCS technology would be evaluated side-by-side with Method 9-certified human observers under regulatory enforcement conditions. The DOCS 1-yr regulatory pilot demonstration study was designed to collect DOCS technology performance data during the air quality enforcement inspection of a range of regulated air sources associated with government and private industrial facilities.

Goal and Objectives

The overarching goal of the DOCS 1-yr regulatory pilot study was to achieve regulatory approval for the use of the DOCS technology to verify compliance with permitted visible opacity limits of stationary air sources. The field demonstration sites selected to support the DOCS 1-yr regulatory pilot study included regulated stationary air sources located at Fort Wainwright, AK, Hill Air Force Base, UT, Fort Hood, TX, and a number of public and private commercial facilities within the state of Utah. The specific DOCS technology demonstration objectives are summarized as follows: (1) collect and compile all opacity field data recorded by the DOCS technology, as well as those readings taken by Method 9-certified human observers under regulatory enforcement conditions; (2) using standard statistical significance testing, evaluate the performance of the DOCS technology relative to Method 9-certified human observers under regulatory enforcement conditions; and (3) based on the DOCS field demonstration results, develop a draft camera-based visible opacity measurement method for review and consideration by EPA.

EXPERIMENTAL WORK

The DOCS 1-yr regulatory pilot field demonstration study was designed to estimate the visible opacity of regulated stationary air sources during Method 9 compliance verification activities at DoD installations located in the states of Alaska, Texas, and Utah, as well a number of public and private commercial facilities within the state of Utah. During DOCS technology field testing, Method 9-certified observers determined the visible opacity associated with specific regulated sources once every 15 sec for a 6-min period. The 24 visible opacity measurements were then averaged and reported as the Method 9 opacity level for the specific air source.

While Method 9 field measurements were being conducted, digital photographs of the visible emissions were taken at the frequency of one photograph every 20 sec for 6 min. At the end of the 6-min measurement period, the 18 digital photographs were evaluated using the DOCS analysis software by personnel from the participating organizations and the results averaged to generate a DOCS technology opacity measurement.

At U.S. military installations, DoD air quality compliance inspectors were responsible for collecting both the Method 9 and DOCS technology opacity measurements. Similarly, at the public and private commercial facilities

within the state of Utah, inspectors from the Utah Division of Air Quality were responsible for determining visible opacity levels using both the DOCS technology and Method 9. All of the field demonstration data collected over the 12-month study (including opacity determinations and digital photographs) were furnished to a DOCS quality assurance team, which had the responsibility of compiling the opacity data for statistical analysis.

DOCS Regulatory and Technical Advisory Panel

Before collection of any field data, a DOCS regulatory and technical advisory panel consisting of experienced EPA scientists and engineers and federal and state air quality regulatory personnel, as well as a number of DoD engineers, scientists, and compliance personnel was constituted to review the scope of the DOCS 1-yr regulatory pilot field demonstration study. The role of the advisory panel was to provide regulatory and technical review and comment on the DOCS technology field demonstration protocol, statistical analysis methods, demonstration study conclusions, and recommendations.

After completion of the DOCS field demonstration data collection activities, the measured opacity of each stationary source as analyzed by the DOCS technology, as well as by Method 9-certified human observers, was furnished to the DOCS quality assurance officer by the participating organizations on a monthly basis and stored in a Microsoft ACCESS database. An assigned quality assurance officer served as the central repository for all of the DOCS technology and Method 9 field data collection, compilation, and quality assurance information. At the request of EPA, monthly conference calls were scheduled for the DOCS regulatory and technical advisory panel to review and discuss results, as well as to modify field data collection procedures, when necessary.

Statistical Test Methods

To establish credible and scientifically defensible arguments that support approval of a new visible opacity test method, data from the DOCS 1-yr regulatory pilot study were compiled and analyzed using standard statistical procedures. During the field data collection activities, the visible opacity measurements reported by the DOCS technology were compared against Method 9-certified visible observers or an EPA-certified transmissometer. By designing the data collection activities to result in paired (or dependent) visible opacity measurements, the impact of factors that might contribute to an observed difference in performance between opacity measurement approaches (e.g., weather conditions) was minimized.

In significance testing, a null hypothesis (H_o) was developed that will be assumed to be true in the absence of strong quantitative evidence to the contrary. The strength of the data may be evaluated statistically using either a paired sample t test or by constructing a confidence interval about the mean difference between the two methods. The results of the paired sample t test and/or the range of the confidence interval will provide the basis for either rejecting or not rejecting the null hypothesis, H_o.

H_o for the present study may be stated as follows: "the true mean difference between Method 9 readings and those reported by the DOCS technology is zero." This statement reflects the decision-maker's conclusion that the two opacity measurement methods are equivalent. Similarly, the alternative hypothesis (H_a) may be constructed as follows: "the true mean difference between Method 9 readings and those reported by the DOCS technology is not zero." If the strength of the data is sufficient to reject the null hypothesis, the decision-maker will conclude that H_a is true. In statistical terms, these hypotheses can be presented as follows:

$$H_o: \delta_o = 0 \text{ and } H_a: \delta_o \neq 0 \quad (1)$$

where δ_o is the true mean difference between opacity readings made by Method 9 and the DOCS technology.

Because the true mean difference between the two visible opacity measurement methods (δ_o) can never be known exactly, it must be determined by calculating the average difference. Equation 2 was used to calculate the average of the paired opacity differences from the sampling data:

$$\bar{d} = \sum_{i=1}^{i=n} \frac{d_i}{n} = \frac{1}{n} \cdot \sum_{i=1}^{i=n} (y_{1,i} - y_{2,i}) \quad (2)$$

where $\bar{d}$ is the average difference between paired opacity measurements; $y_{1,i}$, $y_{2,i}$ is the opacity measurement i recorded by the Method 9 observers and the DOCS, respectively; and n is the number of paired opacity measurements.

Equations 3 and 4 were used to determine the sample variance and standard error of the average differences between opacity readings, respectively. To use the paired t test to draw defensible conclusions from the dataset requires that the decision-maker select a level of significance (α) from which a critical t value may be determined:

$$\textit{Variance: } s_d^2 = \frac{\sum_{i=1}^{i=n} (d_i - \bar{d})^2}{n - 1} \quad (3)$$

$$\textit{Standard Error: } s_{\bar{d}} = \frac{s_d}{\sqrt{n}} \quad (4)$$

where d_i is the difference between paired opacity measurements.

Given an assigned level of significance, α, and degrees of freedom ($n - 1$), the critical t values and test statistic (t_{test}) are defined by the following expressions, which are compared to determine whether the strength of the field data is sufficient to reject the null hypothesis, H_o:

$$\textit{Critical } t \textit{ values: } t_{\frac{\alpha}{2}, n-1} \text{ and } -t_{\frac{\alpha}{2}, n-1} \quad (5)$$

Table 1. Statistical significance testing of DOCS field demonstration data.

Data Type	n[a]	Average Difference[b] (%)	Test Statistic[c]	Critical *t* Value[d]	Rejection of Null Hypothesis
All data	241	−1.12	−41.8	2.576	Yes
All observations where visual opacity was reported to be >0 as measured by Method 9-certified human observers	36	1.20	0.67	2.704	No

Notes: [a]Number of regulated air sources evaluated; [b]Average difference is computed based on the following equation: opacity level (Method 9) − opacity level (DOCS); [c]Computed based on field data; [d]Taken from standard *t* tables assuming a 99% confidence level ($\alpha = 0.01$).

$$\textit{Test statistic: } t_{\text{test}} = \frac{\bar{d} - \delta_o}{\frac{s_d}{\sqrt{n}}} \qquad (6)$$

where δ_o is the true mean difference (assumed equal to zero). Test condition: If $t_{test} > t_{\alpha/2,\, n-1}$ or $t_{test} < -t_{\alpha/2,\, n-1}$, then the null hypothesis, H_o, is rejected.

A method statistically equivalent to the paired *t* test for determining whether the strength of the data is sufficient to reject the null hypothesis involves generating a $(1-\alpha)$ confidence interval about the average difference using eq 7.[10,11] If the confidence interval contains zero, the conclusion will be that, at the stated confidence level $(1-\alpha)$, the true mean difference between the two opacity measurement methods (δ_o) is insignificant, and, therefore, the strength of the data is insufficient to reject the null hypothesis H_o (i.e., the two opacity measurement methods are statistically equivalent).

Conversely, if the confidence interval does not contain zero, the conclusion will be that, at the stated confidence level $(1-\alpha)$, the true mean difference between the opacity readings of the two measurement methods (δ_o) is significant, and, therefore, the evidence is sufficient to reject the null hypothesis, H_o, and the decision-maker will accept the alternative hypothesis, H_a (i.e., the two opacity measurement methods are statistically different), as true.

$$\bar{d} \pm t_{\frac{\alpha}{2},\, n-1} \cdot s_{\bar{d}} \qquad (7)$$

where $t_{\alpha/2}, n-1$ is the critical *t* value from (*t* distribution tables); $\alpha/2$ is the tail area probability; α is the level of significance (i.e., for 99% confidence, $\alpha = 0.01$); $n-1$ is is the degrees of freedom; and $s_{\bar{d}}$ is the standard error of the average differences in opacity readings.

RESULTS

During the DOCS 1-yr regulatory pilot study, the state of Utah Division of Air Quality in conjunction with Fort Wainwright, AK, Hill Air Force Base, UT, and Fort Hood, TX, completed opacity measurements of 241 regulated air processes using both Method 9-certified smoke readers and the DOCS technology. The range of regulated air processes evaluated by the two methods included: (1) industrial process scrubbers, (2) coal-fired boilers, (3) industrial air strippers, (4) industrial bag houses, (5) emergency power generators, (6) asphalt paving operations, (7) oil refining, (8) chlorine manufacturing, (9) steel production, (10) meat packing operations, (11) incineration, (12) gypsum manufacturing, (13) gas/oil distribution systems, and (14) metal coating facilities.

At the recommendation of the DOCS technical and regulatory advisory panel, decisions resulting from these field tests were to be supported at the 99% confidence level; therefore, a significance level (α) of 0.01 was used throughout the analysis. Table 1 provides a summary of the statistical analysis of the DOCS 1-yr regulatory pilot field demonstration study. It should be noted that, in determining the average difference in opacity measurements between the two measurement methods, the DOCS opacity measurement was subtracted from the Method 9 opacity observation. Finally, for the majority of regulated air sources evaluated in the DOCS field demonstration study, a visible opacity level of zero was reported by the Method 9-certified human observers. Table 1 provides a statistical assessment of the two measurement approaches using all of the collected field data (241 regulated air sources), as well as only those regulated air sources that reported nonzero visible opacity levels (36 regulated air sources).

The average difference in opacity readings between the two methods was found to be 1.12% when all of the regulated stationary source opacity data was taken into account. Because the DOCS opacity measurement was subtracted from the Method 9-certified human observer opacity reading, this finding suggests that the DOCS technology reports slightly higher opacity levels than the Method 9-certified human observers. When the dataset was limited to only those regulated stationary sources for which a nonzero opacity level was recorded by the Method 9-certified human observers, the average difference in opacity readings between the two methods was found to be 1.20%, a finding that indicates that Method 9-certified human observers reported opacity values that were slightly greater than those measured by the DOCS technology.

In applying statistical significance testing, the results summarized in Table 1 suggests that, when the opacity data from all 241 of the regulated air sources are taken into account, comparison of the critical *t* value with the test statistic supports the rejection of the null hypothesis. This finding is tantamount to concluding that the two opacity approaches are different and that, on average, the DOCS technology measures visible opacity at a level that is ~1.12% greater than the visible opacity measured by Method 9-certified human observers.

Table 2. Evaluation of the 99% confidence interval about the average opacity difference.

Data Type	n[a]	Average Difference[b] (%)	99% Confidence Interval
All data	241	−1.12	$-1.18 < -1.12 < -1.06$
All observations where visual opacity was reported to be >0as measured by Method 9-certified human observers	36	1.20	$-1.77 < 1.20 < 4.16$

Notes: [a]Number of regulated air sources evaluated; [b]Average difference is computed based on the following equation: opacity level (Method 9) − opacity level (DOCS).

In contrast, when only those regulated stationary air sources for which a nonzero visible opacity was detected by the Method 9-certified human observers are used in the statistical analyses, comparison of the critical *t* value with the test statistic does not support rejection of the null hypothesis. This result indicates that, when measuring nonzero opacity levels, the accuracy of the two measurement approaches is statistically equivalent.

Similar statistically supportable conclusions can be drawn by evaluating the 99% confidence interval about the average difference in opacity readings. Table 2 summarizes the results of this statistical approach. When data from all 241 of the regulated stationary air sources are taken into account, the 99% confidence interval about the average opacity difference extends over a range that does not include the value of zero. In practical terms, this finding supports the conclusion that the two methods are statistically different and that the DOCS technology measures visible opacity at levels that are, on average, 1.12% higher than those reported by Method 9-certified human observers.

Conversely, when only those regulated stationary air sources for which a nonzero visible opacity was measured by the Method 9-certified human observers are included in the statistical analysis, the 99% confidence about the average difference extends over a range that does include the value of zero. The conclusion drawn from this finding is that the two opacity measurement methods are statistically equivalent or, alternatively, there is less than a 1% probability that the two methods are different.[10,11]

DISCUSSION

Although in previous field tests, the DOCS technology had been demonstrated to be an accurate and reliable digital camera-based method for determining the visible opacity associated with stationary air sources, these activities were conducted under relatively controlled conditions. Most of the earlier field data collection was conducted at either an EPA-approved Method 9 smoke schools or at DoD industrial or commercial sites at which plume opacity was controlled by facility personnel.[12]

Recognizing the importance of documenting the performance of the DOCS technology under actual compliance enforcement conditions, EMC in collaboration with several EPA regions and state air regulatory agencies requested implementation of a DOCS 1-yr regulatory pilot study. The data collected during this effort would be used in conjunction with performance data collected in earlier DOCS technology field demonstrations to support the development and promulgation of a new EPA-approved visible opacity measurement method.[13]

The average opacity difference found between the DOCS technology and the Method 9-certified human observers was found to be 1.12%. Although a relatively small difference, statistical analysis of the field data confirmed that the opacity difference was significant. In other words, on average, the DOCS technology would be expected to measure the visible opacity at a level that is 1.12% greater than the Method 9-certified human observer.

Of the 241 regulated air sources evaluated, the majority (205) of air sources were reported to have emissions having no discernable opacity (as recorded by Method 9-certified human observers). Because of the importance of characterizing the opacity measurement response between the Method 9-certifed human observers and the DOCS technology for visible air emissions, the DOCS regulatory and technical advisory panel recommended that a separate statistical comparison be made of those air sources with reported nonzero visible opacity.

Analysis of the 36 regulated air sources for which a nonzero visible opacity level was reported by the Method 9-certified human observers, the average opacity difference found between the DOCS technology and the Method 9-certified human observers was 1.20%. Moreover, based on the results from statistical significance testing, this difference was found to be insignificant. In other words, the small difference found in the average opacity measurements between the DOCS technology and the Method 9-certified human observers could be attributed to random variability (or error) and that the two measurement approaches were statistically equivalent.

Given the successful field demonstration of the DOCS technology under regulatory enforcement conditions, as well as the identification and field validation of commercially available digital camera systems that can support the DOCS technology, EMC in conjunction with DoD has developed a new digital camera-based visible opacity measurement method that, under certain circumstances, may be used in lieu of Method 9.[13] The draft camera-based visible opacity measurement method, which is currently undergoing public comment, is currently on the EPA website.

CONCLUSIONS

The DOCS 1-yr regulatory pilot study was formulated to answer critical questions regarding the performance of

the digital camera-based opacity measurement system under regulatory enforcement conditions. Based on the statistical analysis of the technology demonstration dataset, the following conclusions were supported: (1) over the range of visible opacity of regulatory interest (i.e., 0–40%), the accuracy of the DOCS technology was found to be statistically equivalent to Method 9; (2) over the range of visible opacity of regulatory interest (i.e., 0–40%), the DOCS technology measures visible opacity with an accuracy that was, on average, 1.12% greater than Method 9-certified human observers; (3) based on the successful field demonstration of the DOCS technology, a draft camera-based visible opacity measurement method was developed and submitted to EPA for technical and regulatory review.[13]

Finally, after review of the draft camera-based visible opacity measurement method, EPA issued a preliminary camera-based visible opacity measurement approach titled "Determination of Visible Emission Opacity from Stationary Sources Using Computer-Based Photographic Analysis Systems" (available at: http://www.epa.gov/ttn/emc/prelim/pre-008.pdf). The proposed approach is scheduled to be promulgated in 2006 as a conditional method after completion of the public comment period.

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